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EVALUATION OF GROUND FAULT IN DISTANCE PROTECTION OF TRANSMISSION LINES USING IMPEDANCE CORRECTION ALGORITHM

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ABSTRACT

Distance protection is the main protection of transmission lines and Plays a significant role in power system stabilization and security. This paper is focused on the problem associated with distance Protection of transmission line. Due to the inclusion of fault resistance in the ground faults, the distance relay fails to take correct action for the faults at the end of the first zone and starting of the second zone and the relay either over reaches or under reaches.

It is necessary for the Distance relay to estimate correct impedance up to the fault point excluding the fault resistance. The paper presents impedance correction algorithm that can be used for calculating the magnitude of the apparent impedance. To validate the impedance correction algorithm by simulation has been carried out on transmission line using PSCAD software. The result indicates that the problem of under/over reach has been eliminated.

KEYWORDS: Earth Fault, Fault Resistance, Impedance Correction Algorithm, Distance Relay

INTRODUCTION

In Distance protection, relay uses voltages and currents acquired at the relay location to calculate the apparent impedance of the protected line [1]. The calculated apparent impedance is compared with predetermined impedance than decided status of fault condition.

In the short circuit condition, the current may be limited by fault impedance, which may be composed by three elements: electric arc, tower grounding and ground resistances. Its value might be zero or several hundred ohms. For this reason, fault impedance may be described as an unpredictable quantity.

Thus, calculated apparent impedance by distance relay is combination of the line impedance up to the fault point and fault impedance. So, relay predicted wrong fault location due to inclusion of fault impedance.

We have to design an algorithm which is gives correct impedance value up to the fault location. The algorithm is excepted to correct the value of fault impedance in the measured apparent impedance. So it`s called impedance correction algorithm.

EFFECT ON IMPEDANCE DUE TO FAULT RESISTANCE AND DOUBLY FED TRANSMISSION LINE

For doubly fed transmission line shown the figure 1, the voltages at the relay location (S) can be expressed as functions of relay current (I_S) and voltage at the fault point (F).

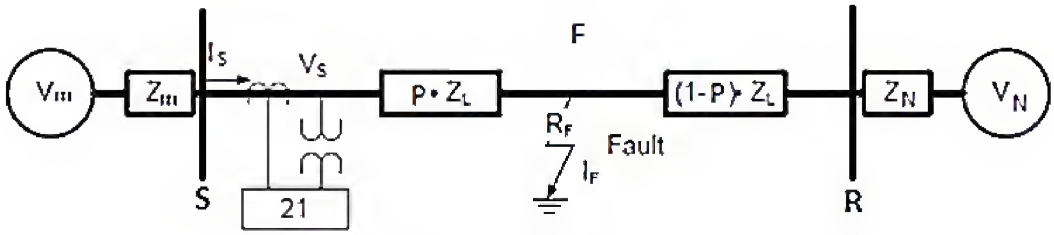


Figure 1: Doubly Fed Transmission Line

The voltage at the relay is

$V_S = I_S \cdot p \cdot Z_L + I_F \cdot R_F$

$V_S = I_S\,(p \cdot Z_L + \frac{I_F}{I_S} \cdot R_F)$

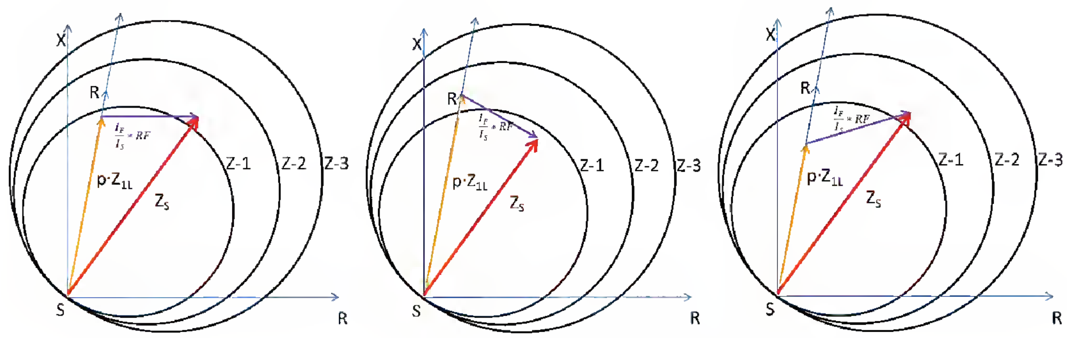
And the apparent impedance is

$Z_S = (p \cdot Z_L + \frac{I_F}{I_S} \cdot R_F)$

Where, p = percentage of protected line.

Z_{1L} = Positive sequence impedance of line.

At no load, I_F and I_S are in phase and the fault resistance will push the apparent impedance to the right as depicted in Figure 2. So our fault point is shifted on right side up or down position depended on I_S and I_F [3].



No Load Export Power Import Power

Figure 2: Impact of the Fault Resistance and through Fed-On Conditions on Apparent Impedance

When load is flowing out of the terminal (export) the fault resistance will be shifted down on the R-X plane; causing a static distance element to under-reach. When load is flowing into the terminal the fault resistance is shifted up on the R-X plane causing a static distance element to over-reach. So the relay gives wrong operation due to point shifting [3].

If the fault occurs in zone 2 then, the point is shifted right side down so relay considers fault in zone 1. So relay is operated instantly. If the fault is occurs in zone 1 end then the point is shifted right side up so relay consider fault in zone 2. Hence relay is operated with time delay.

The fault resistance has little effect on accuracy of zone-1 unit as it operates instantaneously before the arc can stretch appreciably except in case of short lines. Reactance relays are therefore used for short lines where the fault resistance may be comparable with that of the protected lines and also for ground faults where the ground resistance is

high. The fault resistance will have greater impact on accuracy of backup zones (time delayed) as the arc stretches appreciably [4].

ANALYSIS OF GROUND FAULTS ON DOUBLY FED TRANSMISSION LINE

Figure 3 shows a line diagram of a portion of the power system network having a transmission line between two buses. A single-line-to-ground fault, having fault resistance occurs at fault location which is at p percentage of the transmission line from bus s. Since part of the fault current supplied from bus is not correctly measurable at the relaying point, the conventional ground distance relay measures an incorrect value of fault impedance. So, the relay may over-reach/under-reach depending upon the export/import of power flow and the magnitude of fault resistance [2].

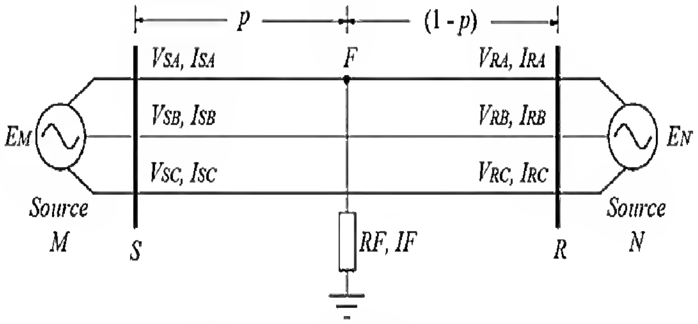


Figure 3: Modeling of the Single-Line-to-Ground Fault

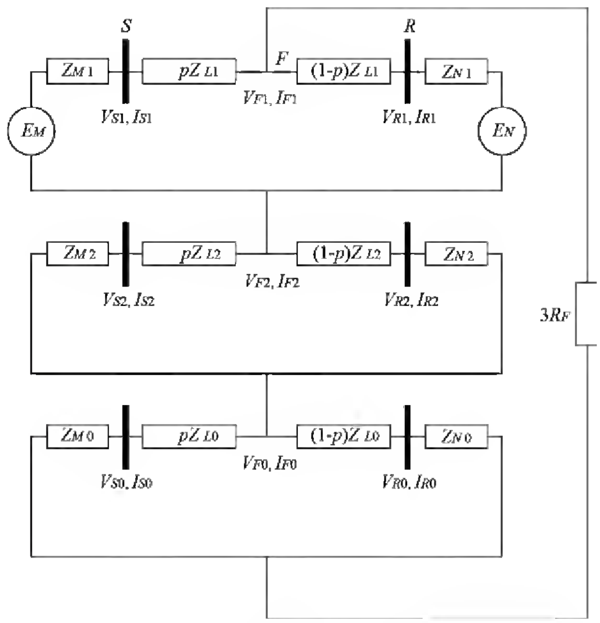


Figure 4: Equivalent Circuit for the Single-Line-to-Ground Fault in Phase A [2]

For all analyses, positive and negative sequence impedances (Z_{L1} and Z_{L2}) of the transmission line are assumed to be equal. Position negative sequence diagram is presented in figure 4. The voltage and current of phase A of the transmission line measured at the relaying point S are represented by V_{SA} and I_{SA}, respectively.

Based on positive negative sequence diagram value of I_{S0} is

$$I_{S0} = \frac{Z_{N0}+(1-p)Z_{L0}}{Z_{M0}+Z_{N0}+Z_{L0}} I_{F0}$$

Generally, the magnitudes of Z_{M0} and Z_{N0} are negligible with respect to Z_{L0}. Further, it appears in both numerator and denominator side. Therefore, Z_{M0} and Z_{N0} can be safely removed from the equation. Hence, we can be written as

$I_{S0} = (1\text{-}p)\, I_{F0}$

The sequence current components during a single line to-ground fault at point F are equal ($I_{F1} = I_{F2} = I_{F0}$). The total fault current is given by [2]

$I_F = I_{F1} + I_{F2} + I_{F0} = 3^*\, I_{F0} = \frac{3}{(1-p)} I_{S0}$

Impedance measured by the conventional Ground Distance Relaying Scheme Referring to Figure 3, for a single-line-to-ground fault of a doubly fed transmission line, the fault impedance Z_{SA} seen by the conventional ground distance relaying scheme located at relaying point S is given by

$Z_{SA} = \frac{V_{SA}}{I_{SA}+(K_0 \times I_{S0})}$

$= (p \times Z_{L1}) + Z_F$

Where,

$K_0 = \left(\frac{Z_{L0} - Z_{L1}}{Z_{L1}}\right)$

$Z_F = \frac{I_F \times R_F}{I_{SA} + (K_0 \times I_{S0})}$

IMPEDANCE CORRECTION ALGORITHM FOR SOLVING FAULT RESISTANCE PROBLEM

Step 1

Measure the 3 phase voltage and current at the relaying point than give suitable quantities to particular relay as per phase and ground relay. The algorithm is developed for implementing in the ground relay.

Step 2

We have known value of resistance (R_T) and reactance (X_T) of transmission line. Find the equation of line impedance using R_T and X_T.

$Y = m_1{*}x + c_1$

$X_T = m_1{*}R_T + 0.$

Hence, $m_1 = \frac{XT}{RT} = \tan \Phi$

Where, c_1 is zero because line intersects to origin of the plane.

Finally we got the equation of line SR as

$Y = \tan \Phi\, {*}x$ A

Step-3

Find the impedance Z_{SA}, Z_{SB} and Z_{SC} using their equation. Here only phases A is considered, other phases have similar procedure for calculation. Z_{SA} intercept on X axis and Y axis gives the value of R_{SA} and X_{SA} respectively.

Step-4

Z_{SA} is combination of Z_P and Z_F. Z_P is same as $p*Z_{L1}$ lead to X axis by Φ angle and Z_F is lag to X axis by α angle. But Z_F is depend on I_F and I_R.

$$Z_{SA} = Z_P + Z_F$$

$$Z_{SA} = (p \times Z_{L1}) + \frac{I_F \times R_F}{I_{SA} + (K_0 \times I_{S0})}$$

$$= (p \times Z_{L1}) + \frac{3}{(1-p)} \cdot \frac{I_{S0} \times R_F}{I_{SA} + (K_0 \times I_{S0})} \qquad \text{B}$$

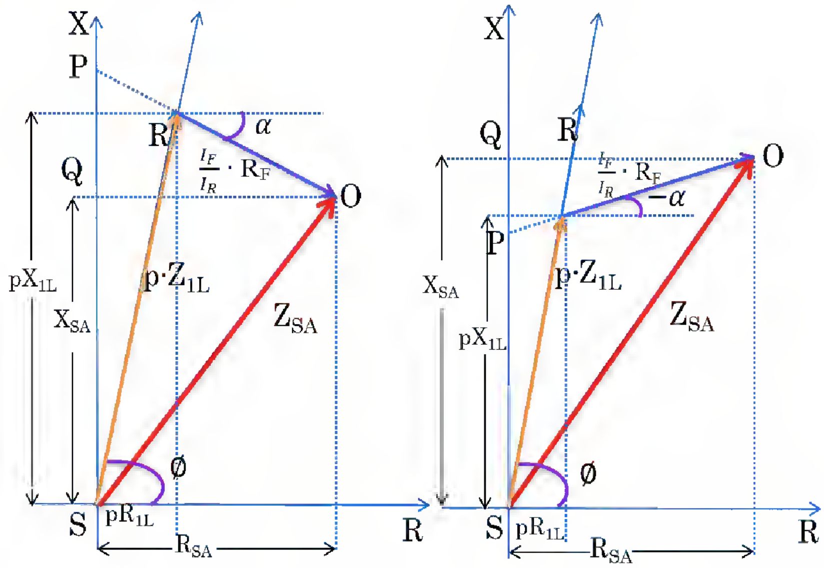


Figure 5: Impedance Seen at the Relaying Point S for a Single-Line-to-Ground Fault [2]

Here, the values of R_F and p are real but they are unknown. Their values depend on fault resistance and fault location on transmission line. The angle of Z_{L1} is known. It is drawn in phasor diagram at Φ angle.

I_{S0} is the zero sequence current. It is measured from line current using numerical relay. K_0 is also sequence component of line impedance it is calculated from transmission matrix. I_{SA} is already measured so we can easily find the angle α.

$$\angle \alpha = \angle \left| \frac{I_{S0}}{I_{SA} + (K_0 \times I_{S0})} \right|$$

Step-5

Find the line equation of line OP using R_{SA}, X_{SA} and tan $(-\alpha)$.

$$Y = m_2 * x + c_2$$

$$\text{Tan}(-\alpha) = m_2$$

$X_{SA} = \tan(-\alpha) * R_{SA} + c_2$

$C_2 = X_{SA} - \tan(-\alpha) * R_{SA}$.

Finally the equation of line OP is get

$Y = \tan(-\alpha) * x + X_{SA} - \tan(-\alpha) * R_{SA}$ C

Step-6

Find the intersection point of line OP and SR from Equation A and C.

$Y = \tan \Phi * x = \tan(-\alpha) * x + X_{SA} - \tan(-\alpha) * R_{SA}$

$\mathrm{Tan}\, \Phi * x - \tan(-\alpha) * x = X_{SA} - \tan(-\alpha) * R_{SA}$

$X = \frac{X_{SA} - \tan(-\alpha) * R_{SA}}{\mathrm{Tan}\, \Phi - \tan(-\alpha)} = p * R_{L1} = Ra0new$ D

$Y = \tan \Phi * \left(\frac{X_{SA} - \tan(-\alpha) * R_{SA}}{\mathrm{Tan}\, \Phi - \tan(-\alpha)}\right) = \tan \Phi * Ra0new = p * X_{L1} = Xa0new$ E

Step-7

Base on $p*R_{L1}$ and $p*X_{L1}$ we calculate the $p*Z_{L1}$

$P*Z_{L1} = \sqrt{(PR_{L1}{}^{2} + PX_{L1}{}^{2})}$

Step-8

Repeat the step-1 to step-7 for $p*Z_{L1}$ values more than the set value as per zone impedance otherwise stop and give the trip signal to the circuit breaker for operation.

This Algorithm is implemented on a doubly fed transmission line and Simulations are carried out by PSCAD Software.

SIMULATION RESULTS

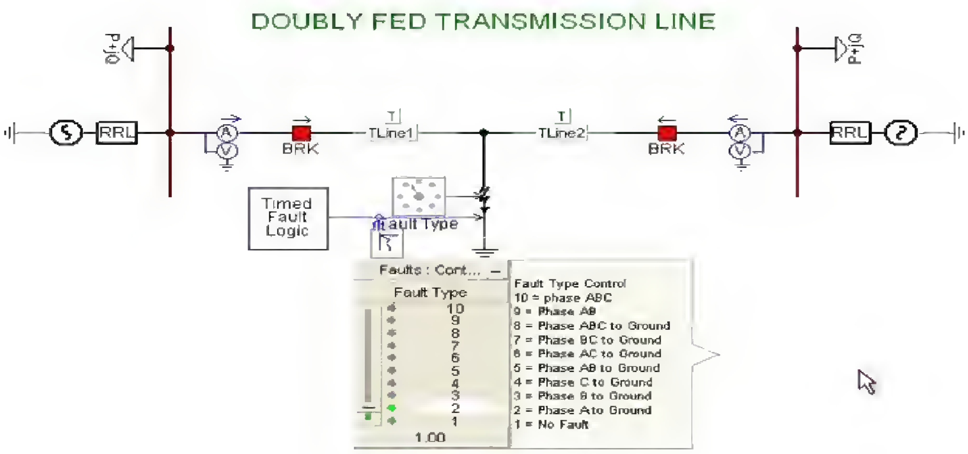


Figure 6: Simulation Diagram of Doubly Fed Transmission Line in PSCAD Software

As shown in figure 6 two bus 400kv, 50Hz power system [6] with generating station and load on both buses and it`s connected using 160 km long transmission line.

Table 1: Transmission Line Sequence Impedance

	R (Ω)	X (Ω)	Z (Ω)	ϕ (degree)
Positive Sequence	63.24	85.31	106.19	53.45°
Negative Sequence	63.24	85.31	106.19	53.45°
Zero Sequence	190.84	75.87	205.36	21.68°

Figure 7 Indicates the Impedance diagram of the mho relay for fault on 70% of transmission line from the relay location. Here blue color Point (outside the mho circle) indicates the measured impedance by conventional relay and pink color point (inside the mho circle) indicates impedance value which is given by impedance correction algorithm. Shown in the figure conventional relay doesn`t give any trip signal to the breaker, but impedance correction algorithm gives trip signal to the breaker for the operation as per the protection philosophy.

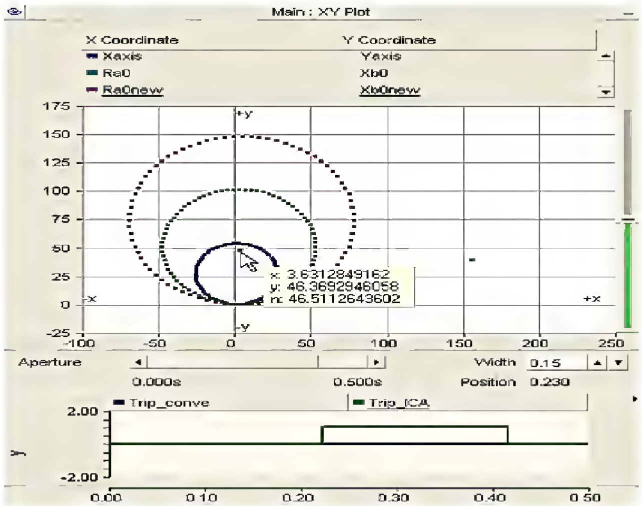


Figure 7: Impedance Diagram for Fault at 70% of the Transmission Line from the Relay Location

Table 2 indicates Simulation result of phase A to ground fault for the Fault Resistance (R_f) =100 ohm. Table 2 shows the Simulation Results measured for the fault location from 0% to 100% of transmission line in Steps of 10%

Table 2: Simulation Result of Phase A to Ground Fault for the Rf =100 ohm [5]

%p	R_{line}	X_{line}	Z_{line}	R_m	X_m	Z_m	%errZ_m	R_{ica}	X_{ica}	Z_{ica}	%errZ_c
0	0	0	0	91.71	5.96	91.90	-	0.202	6.776	6.77	-
10	0.549	6.701	6.72347	95.30	7.28	95.57	1321.5	0.418	9.045	9.05	34.53
20	1.099	13.402	13.4469	102.58	12.31	103.3	668.32	0.983	16.514	16.5	22.81
30	1.648	20.103	20.1704	110.68	18.24	112.1	456.13	1.536	22.323	22.3	10.67
40	2.197	26.804	26.8939	119.90	23.97	122.2	354.65	2.051	26.473	26.5	1.57
50	2.747	33.505	33.6174	130.38	29.40	133.6	297.57	2.572	31.034	31.1	7.68
60	3.296	40.206	40.3408	142.46	34.49	146.5	263.34	3.087	41.244	41.3	2.24
70	3.845	46.907	47.0643	156.75	39.14	161.5	243.28	3.631	46.369	46.5	1.48
80	4.395	53.608	53.7878	175.56	42.89	180.7	235.99	4.167	52.448	52.6	2.49
90	4.944	60.309	60.5113	194.20	45.60	199.4	229.66	4.692	57.987	58.1	4.17
100	5.493	67.010	67.2347	206.90	47.80	212.3	215.83	5.586	63.076	63.3	6.19

Where, p = Percentage of protected line

R_{line}= Resistance of line up to the fault

X_{line}= Reactance of line up to the fault

Z_{line}= Impedance of line up to the fault

R_m = Measured Resistance by conventional relay

X_m = Measured Reactance by conventional relay

Z_m = Measured Impedance by conventional relay

%errZ_m = Percentage of error in X_m = $\left|\frac{Z_m - ZX_{line}}{Z_{line}}\right| * 100$

R_{ica}= Resistance by Impedance correction algorithm

X_{ica}= Reactance by Impedance correction algorithm

Z_{ica}= Impedance by Impedance correction algorithm

%errZ_c = Percentage of error in Z_{ica} = $\left|\frac{Z_{ica} - Z_{line}}{Z_{line}}\right| * 100$

CONCLUSIONS

This paper is solving a problem associated with fault resistance for a Line to ground fault condition on transmission line. Due to fault resistance included, measuring impedance relay often mal-operates in the selection of zone or operating time interval. Impedance correction algorithm correctly finds the impedance to a fault point without including the fault resistance. So, that the relay can be operated as per the required protection philosophy. In this paper impedance correction algorithm is described in detail. Simulation of the impedance correction algorithm is done in PSCAD software on a long transmission line. It gives better efficiency compared to the conventional method and the fault resistance is measured nearly zero ohm.

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